Influence of Low Callisto Orbit design on gravity field recovery

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Orbit characteristics	Max. degree
88° 200x200km	70
88° 400x400km	45
112° 400x400km (SSO)	18
88° 400x1400km	19

Maximum spherical harmonic degree of gravity field recoverable for low Callisto orbits, with different inclinations and altitudes for a duration of 90 days

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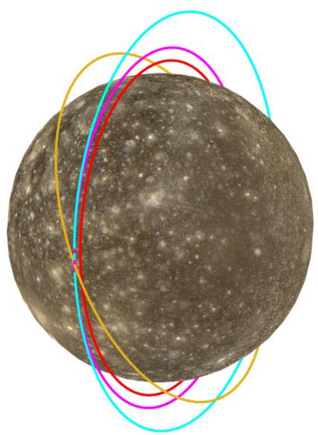
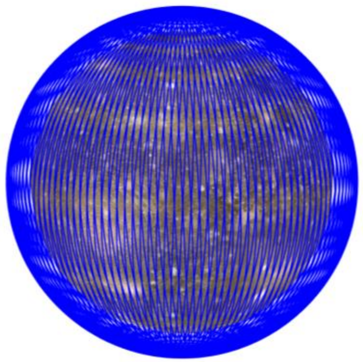
Introduction and Background

- Gan De is a Chinese exploration mission under study, that would fly to Jupiter in the 2030's [3]. An orbiter would be injected into a Low Callisto Orbit to perform an extensive characterization of its surface and interior, investigate its degree of differentiation and search for the possible existence of an internal ocean.
- After an extended tour of the Jupiter system, a first polar elliptic orbit is foreseen for capture around Callisto. Then two polar circular orbits could be used for science investigation. A first one for at least 6 months, and a second one with lower altitude, with the possibility of regular manoeuvres to counteract orbit decay.
- Here, more specific orbits are also investigated due to their relevance for mission design:



  - Sun synchronous orbits (SSO): constant angle between Sun and orbital plane, but with an important polar gap and highly dependent on the gravity field knowledge at low altitude.
  - Repetitive Ground Track Orbits (RGTO): defined by an integer triplet (N,P,Q) [4], fixed phase grid defined for N*P+Q orbit revolutions during P Callisto days [5].



- Orbit propagations in a full force model, as well as the whole gravity field recovery process were done using a development version of the Bernese GNSS Software [6].

Set of orbits and simulation setup

Altitude	Inc.	RGTO	SSO
200x200km	88°	No	No
200x200km	88°	(146,1,0)	No
197x197km	88°	(146,5,1)	No
395x395km	88°	(131,1,0)	No
401x401km	112°	No	Yes
400x1400km	88°	No	No

Set of 6 orbits under study. All have a 45° β_{Earth} angle (between orbital plane and Earth)

Simulation flow chart (for each orbit)

Initial condition

90/200 days propagation from 01-May-2031

Daily initial conditions

$\sigma_p = 50$ m
$\sigma_v = 1$ mm/s

2-way Doppler X-band obs. *

$\sigma_{obs} = 0.1$ mm/s at $\tau = 60$s

- 3rd body perturbations: Sun, planets, Galilean moons
- Jupiter gravity field: J_2 to J_6
- Tides from Jupiter: $k_2 = 0.0$

Reference Callisto gravity field:
- d/o 2: Anderson et al (1998) [1]
- d/o 3 to 50/90: scaled Moon's field

Generalized orbit determination (Celestial Mechanics Approach [2])

(***)

Daily normal equations

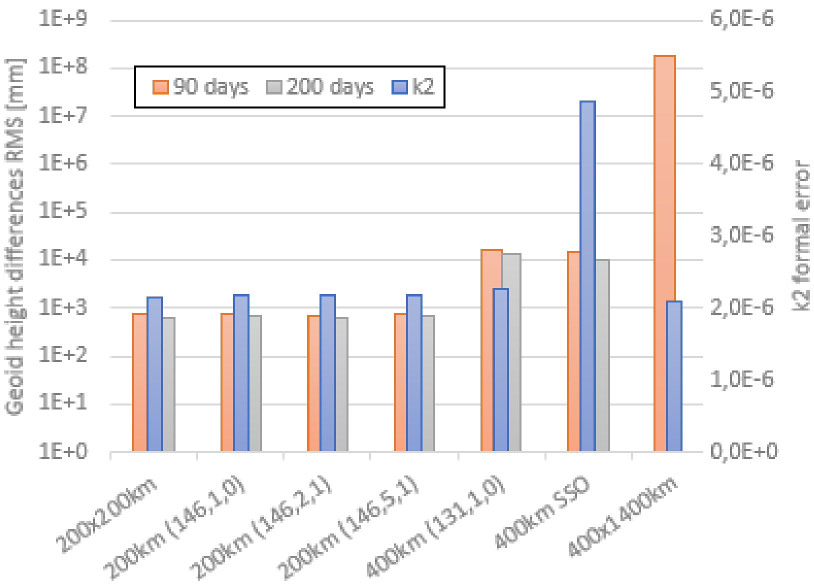
Stacked normal equation (90/200 days)

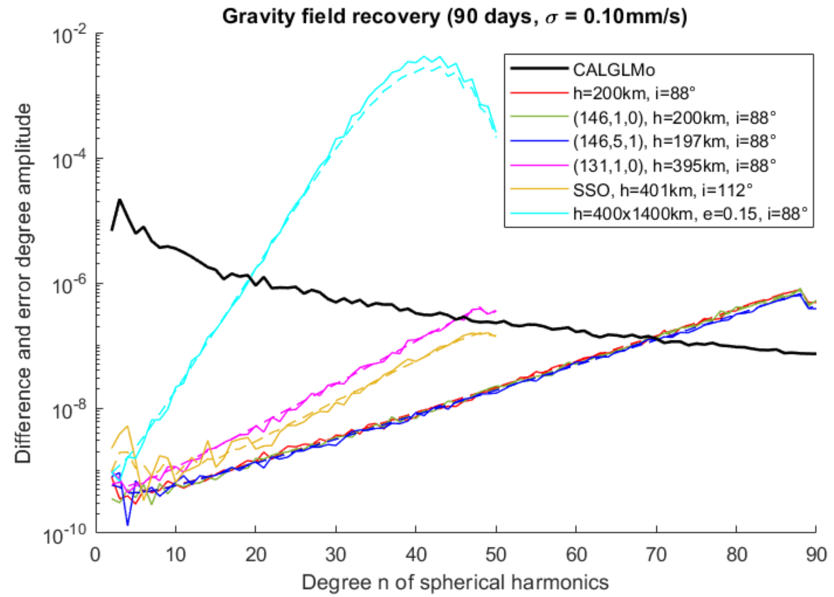
k_2 and gravity field solution **

Comparison: $\Delta\bar{C}_{nm}, \Delta\bar{S}_{nm}, \Delta g_{\theta,\phi}$

** : Generated with a full coverage of 3 Deep Space Network stations*
*** : Coefficients are estimated freely in only one iteration*
****: Tests have been made with degraded a priori gravity field, requiring then several iterations*

Gravity field recovery





Weighted RMS of geoid height differences $\Delta g_{\theta,\phi}$ for 90/200 days ($\sqrt{\frac{\sum_{\theta,\phi}\cos(\theta)\Delta g^2_{\theta,\phi}}{gridsize}}$) and k_2 Love number formal error for 90 days mission computed using an a priori d/o 50 field.

Difference (solid) and error(dashed) degree amplitudes ($M_n = \sqrt{\frac{\sum_{m=2}^{n}(\Delta\bar{C}^2_{nm}+\Delta\bar{S}^2_{nm})}{2n+1}}$). For 200km orbits, the gravity field was estimated up to d/o 90

- 22° polar gap is omitted for the Sun Synchronous Orbit
- With face-on orbit, the gravity field recovery is worse. As an example, the (146,1,0) orbit leads to a larger weighted RMS of geoid height difference for β_{Earth}=90° (153cm) than for β_{Earth}=45° (88cm).
- Using a d/o 40 truncated gravity field with the 200km (146,1,0) orbit, 4 iterations on the gravity field solution are needed to reach the solution computed with a full d/o 50 a priori gravity field.

Conclusions

- A highly eccentric orbit over a time span of 90 days can already improve the knowledge of Callisto's gravity field (up to d/o 19 for a 400x1400km orbit). However, as the eccentricity increases significantly with time, such an orbit is not stable for more than 3 months.
- Sun synchronous orbits suffer from a large polar gap, the recovery of zonal coefficient is then largely impacted, just as Love number k2 recoverability.
- For all non-Sun synchronous orbits, β_{Sun} does not vary much (max. 1.2°/month). A SSO for maximum illumination might then not be compulsory.
- Low altitude polar orbits are the best suited for gravity field recovery. At 400km altitude, one can expect to recover the gravity field up to d/o 45 after 90 days.
- Lower orbits are even more beneficial, but will require manoeuvres to increase the orbit lifetime. Repetitive Ground Track Orbits are well suited to efficiently plan station keeping manoeuvres.
- For 200km polar orbits a sensitivity up to d/o 70 was found after 90 days. In the case of Callisto, the effect of low density ground tracks (for RGTO) is negligible.

Acknowledgements & References

Acknowledgments

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